Integration of the Inertial Electrostatic Confinement Diffusion Thruster for Testing

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The Inertial Electrostatic Confinement Diffusion Thruster is an experiment in active development that takes advantage of physical phenomenon that occurs during operation of an Inertial Electrostatic Confinement (IEC) device. The IEC device is a fusion reactor design that relies on traditional electrostatic ion acceleration and is typically arranged in a spherical geometry. The design incorporates two radially-symmetric spherical electrodes. Often the inner electrode utilizes a grid of wire shaped in a sphere with a radius 15 to 50 percent of the radius of the outer electrode. The inner electrode traditionally has 90 percent or more transparency to allow particles (ions) to pass to the center of the spheres and collide/recombine in the dense plasma core at *r*=0. When operating the IEC, one can observe an unsteady plasma leak. The plasma leak passes out one of the gaps in the lattice grid of the reactor's inner electrode. It has been postulated that this plasma leak can be used for propulsive purposes.

The Inertial Electrostatic Confinement Diffusion Thruster utilizes the radial symmetry found in the IEC device. A cylindrical configuration is employed here as it will produce a dense core of plasma the length of the cylindrical grid while promoting the plasma leak to exhaust through a nozzle at one end of the inner electrode. A prototype IEC Diffusion Thruster is operational and under testing using argon as propellant and considerations are being made to upgrade hardware to allow measurement of thrust.

Nomenclature

IEC	=	Inertial Electrostatic Confinement
MSFC	=	Marshall Space Flight Center
UAH	=	University of Alabama in Huntsville

I. Introduction

ADVANCED propulsion research today extends to chemical power systems, nuclear thermal rockets, solar and laser power systems, fusion power systems, electric propulsion, and others. At Marshall Space Flight Center (MSFC) one area of research involves the development of an electric thruster based on a fusion reactor concept.

Traditional chemical propulsion systems use combustion to release energy. A fuel and oxidizer mixture ignites to release energy stored in chemical bonds. The energy is then used to heat and expand the chemical products through a nozzle. The specific impulse of such systems is at best about 450 seconds while the thrust can range from newtons to millions of newtons of force.

Electric propulsion (Jahn, 2006) is accomplished using electrical energy to accelerate propellant using an electromagnetic field. The electrical energy can be generated from combustion, nuclear, solar, or stored energy sources and then used in the thruster. Specific impulses between 1000-10,000 seconds are easily attainable, with thrust levels from sub-millinewtons to hundreds of newtons of thrust, depending upon the amount of power available. Though electric propulsion does not have the thrust to compete as an Earth-ascent thruster, it has various critical applications in orbit transfers and station keeping, and is well-suited for missions to a variety of deep-space destinations.

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II.   The Inertial Electrostatic Confinement Device

At MSFC, research has been completed using the Inertial Electrostatic Confinement Device (IEC) (Dobson, 2004). This researched analyzed the density of the plasma when the IEC was using argon as a propellant then deuterium as a propellant. The IEC is designed as Hirsch–Meeks fusor (Figure 1).

When operating the IEC with argon, a plasma leak is visible. As the pressure of the plasma core increases, the neutralized propellant seeks for a route to the low pressure area outside the inner electrode. Often, an inconsistency in manufacturing leaves the electrode to have a non-symmetric grid. The leak tends towards the larger grid openings. This observation calls for an investigation of a potential thrust application. The gas will ionize and current will flow at 2.5 kV and 30 mA.
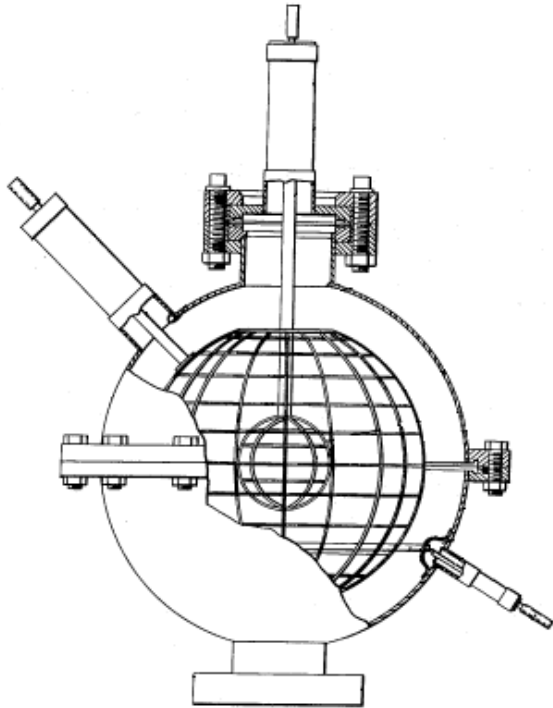
Figure 1 - Hirsch–Meeks Fusor

The two concentric electrodes can be seen in the center of the reaction chamber. From US patent 3,530,497.
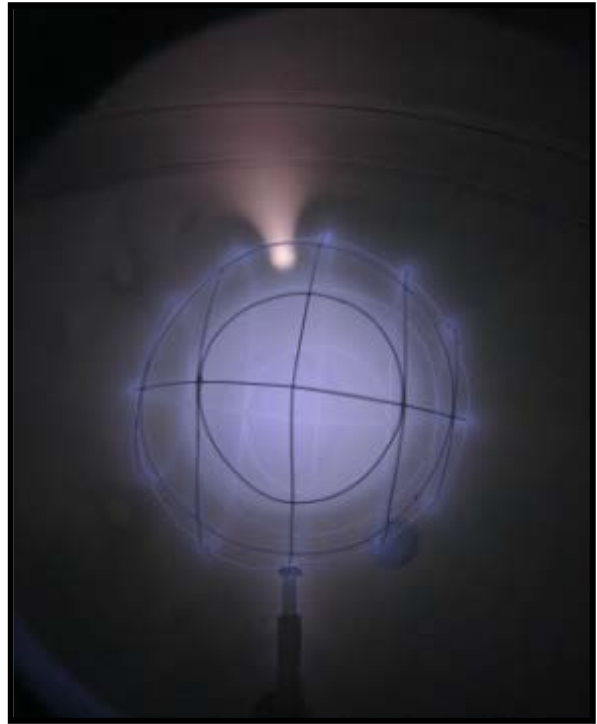
Figure 2 – IEC

IEC operating with plasma jet 'leak' visible.

III.   Design of a Thruster

When designing the IEC Diffusion Thruster, certain geometric and electric properties of the IEC must be conserved. First, the radial symmetry of the electrodes should be preserved for the propellant to form a dense region in the core of the apparatus. The dense area of the IEC can be observed within the inner electrode where recombination occurs (Figure 2). Radial symmetry is found in both spherical and cylindrical design.

The inner electrode must have 90 percent or more transparency for ions to enter the core region of the device. To accomplish this, the inner electrode must have grid wires of reasonable diameter and positioned properly to ensure there is at least 90 percent open area on the inner electrode.

For a thruster design, the plasma leak must be induced in a repeatable position. The leak also needs to escape the strong potential well of the electrodes. The material must be a good conductor and not erode quickly when in use. All supporting structures should be made of a good, high-temperature insulator that can resist plasma sputtering. Electrodes must be connected and shielded to not interfere with electrode design.

Taking these factors into consideration, a cylindrical configuration was chosen. For the outer electrode, the linear distance will scale the propellant flux into the central core. A spherical grid cover will be installed on one end of the cylinder to create a consistent electric field. A partial spherical grid will be installed on the exit-end of the cylinder to act as a nozzle for the exhaust. For the inner electrode, a simple grid cylinder will be formed the length of the outer cylinder. One end will have a bolt point for the power connection. The manufactured design is dimensioned in Appendix A. Later iterations can incorporate magnetic bottles and nozzles to help with plasma

extraction and thrust production.

IV. Manufacturing

Manufacturing must be considered in material selection. Initial design is based on the IEC electrode, fabricated with 304 stainless steel. To conserve on manufacturing costs, the researcher chose to take raw stock of stainless rod and form the electrodes. At the UAH Engineering Design and Prototyping Lab, an ABS plastic frame was rapid prototyped to support the steel structure in welding and for installation in the chamber.
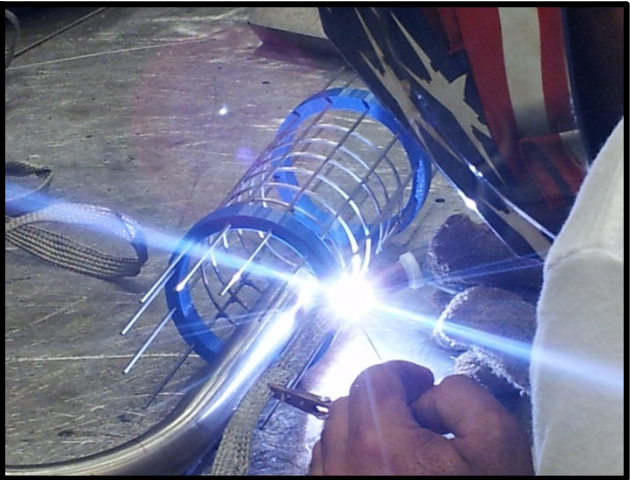
Some problems were encountered in the manufacturing process. Because the rings were difficult to form at the smaller diameter of 2 cm, a plate was machined into simple rings. This was possible, but consumes tooling in the milling operation. During welding, the design was not tolerant of the rings of stainless being under tension. If a ring was in tension, a weld would cause the ring to break open. The ABS welding jig, especially for the small inner electrode, melted to the metal. This permanently damaged the small steel grid spacing.

These manufacturing issues led to the consideration of a different fabrication technique. At MSFC, the National Center for Advanced Manufacturing operates the Electron Beam Melting machine. This device printed the inner electrode out of titanium. This use of this advanced, rapid-prototyping manufacturing technology was able to expedite manufacturing of the thruster.
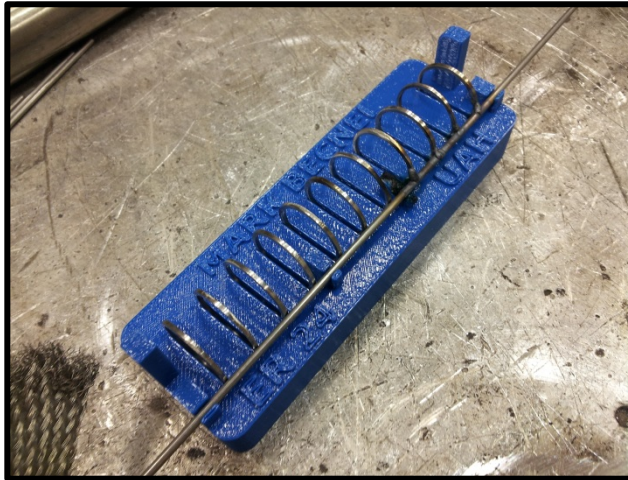
Figure 3 - Inner Electrode   **Figure 4 - Outer Electrode**

The blue is an ABS Plastic jig for welding.

V. Integration into Testing Environment

With the electrodes successfully manufactured and mounted, the last step is to prepare and integrate with the vacuum chamber. The chamber has five view ports positioned around the device. The thruster should be aligned with these ports to accommodate visual observation of the experiment. An insulated mount will both isolate the thruster from the chamber and lift the thruster to a good height for the view ports. (Figure 5, 6)

There are multiple feed through ports, which can accommodate various connections. One port is fitted with propellant plumbing. The feed will pump propellant into the chamber as a backfill, so no plumbing is necessary inside the chamber. Outside the chamber, a mass flow controller regulates the flow of argon. One port is fitted with electrical connections. With special care being taken to prevent arcing in a vacuum, the positive lead of the power supply is connected to the outer grid and the negative lead is connected to the inner grid. The power supply can provide the necessary 2.5 kV and 30 mA; the negative lead is isolated away from ground. Heat produced is assumed negligible for the short duration tests of less than one minute. In the future, thermal imagery will provide insight on the temperatures reached by the structure during operation.

Figure 5 - Testing Vacuum Chamber
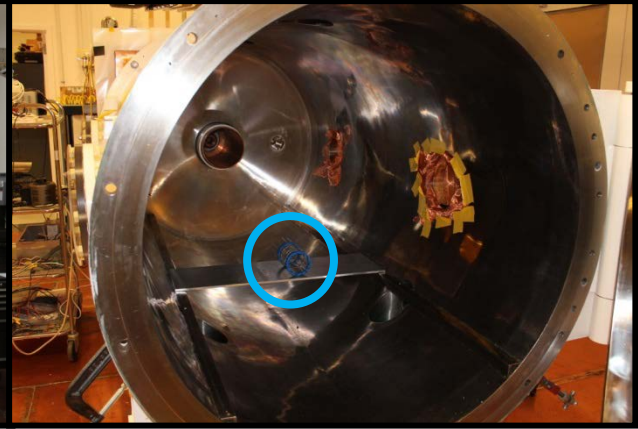
Figure 6 - Inside Testing Vacuum Chamber
Note: thruster place on support plate for scale.

VI.   Test Results

Qualitative results of testing with the IEC Diffusion Thruster shows recombination does occur in the core of the thruster. The dense area is observed to immediately exhaust axially. At lower pressures, the exhaust does form in the wrong direction, however with more pressure, the exhaust flips to the expected side of the device. This inconsistency at lower pressures is likely do to imperfect manufacturing of the grid dimensions in the initial prototype, where the inner electrode is not positioned precisely in the center of the device. (Figure 7,8,9)
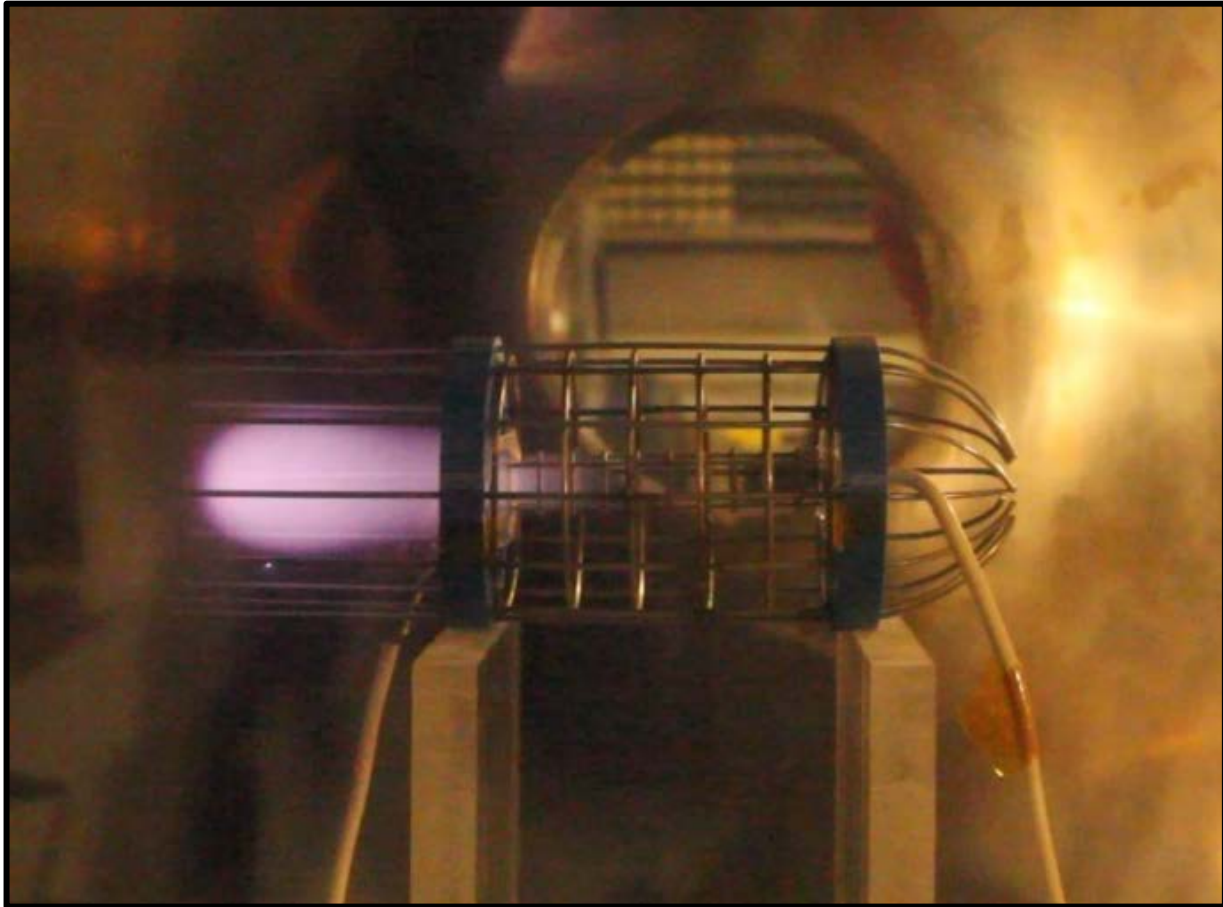

Figure 7 – Front End
Plasma located at front end of electrode grids

Figure 8 –Back End
Plasma located at back end of electrode grids

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Figure 9 – IEC Diffusion Thruster, Nominal Operation

VII.   Conclusions

The IEC Diffusion Thruster design shows promise as a possible electric propulsion option. The device is now being upgraded to offer a more consistent grid alignment and fitted with a glass boundary to contain and direct a flowing gas towards the exit. This improvement should offer better use of propellant and will permit flow-through operation. Quantitative measurement of thrust will be completed as the design is finalized. This will be accomplished with a hanging-pendulum thrust stand.

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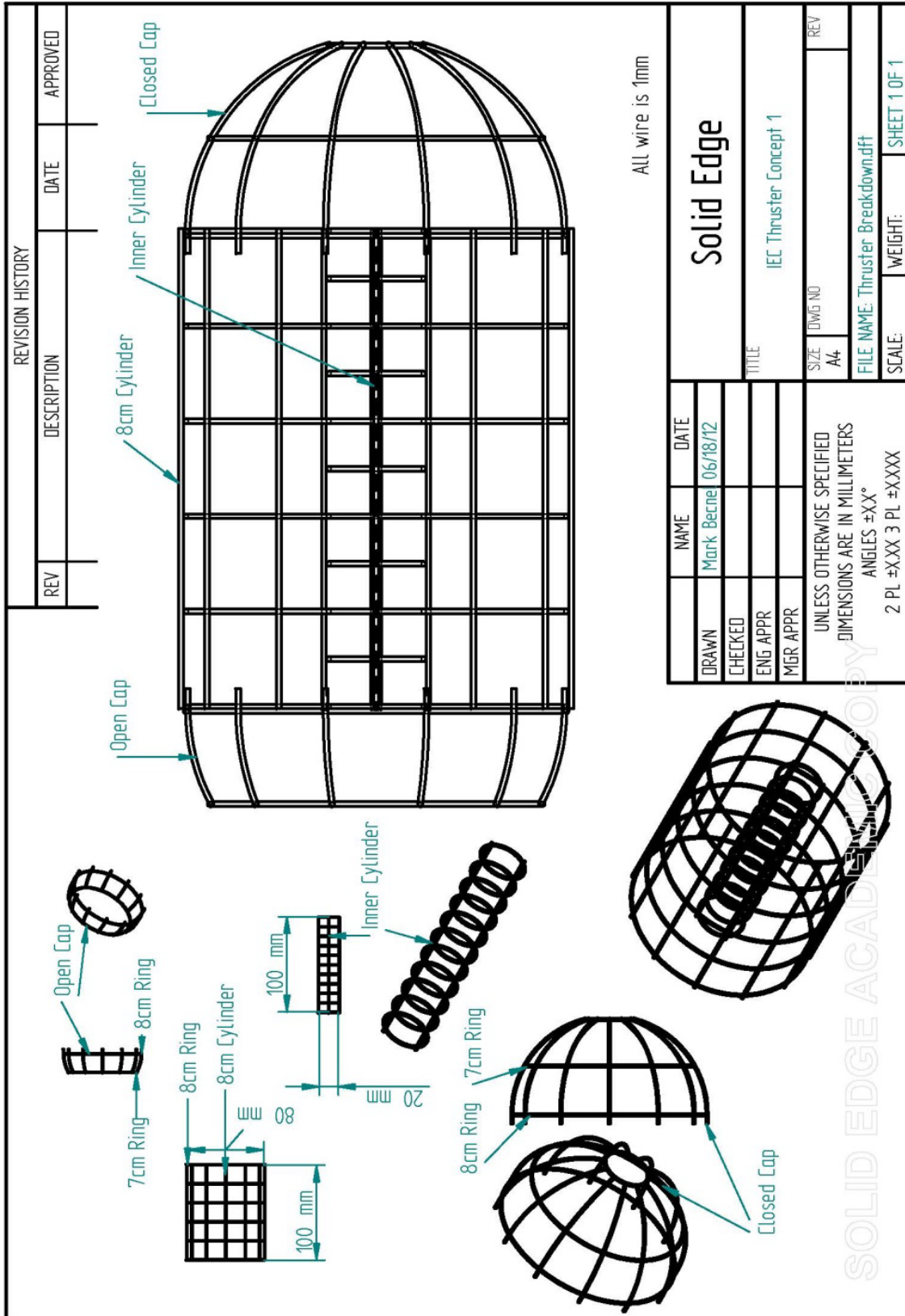
Appendix A

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Acknowledgements

References

Dobson, C. a. (2004). Electron density and two-channel neutron emission measurements in steady-state spherical inertial-electrostatically confined plasmas, with review of the one-dimensional kinetic model. *Journal of Applied Physics, 96*(1).

Jahn, R. G. (2006). *Physics of Electric Propulsion.* Dover.